Broadband Inversion in Shallow Water

Michael B. Porter
Science Applications International Corp.
888 Prospect St., Suite 201
La Jolla, CA 92037
phone: (858) 826-6720 fax: (858) 826-2700 email: michael.b.porter@saic.com
Award Number: N00014-95-1-0558
http://oalib.njit.edu

LONG-TERM GOALS

Largely because of the exponential growth in computer technology, we can now embed sophisticated acoustic models in SONAR and ocean-observing systems. I would like to do this in a physics-based sense, with an understanding of what acoustic features can *reliably* be exploited in the signal-processing algorithms.

OBJECTIVES

The specific objectives are to: 1) study acoustic propagation in topographically and oceanographically complex areas; 2) to identify robust features in the channel response; 3) enhance the acoustic channel-models for efficient prediction of these features; and thereby 4) to design robust signal-processing algorithms to both track quiet sources and observe the marine environment.

APPROACH

The experimental component is central to this effort and I've been working with several programs. A pilot experiment called INTIMATE96 (Internal Tide Monitoring by Acoustic Tomography Experiment) was conducted in collaboration with scientists from France (Y. Stephan, SHOM/France) and Portugal (S. Jesus, University of Algarve, Portugal). This experiment [1] was conducted in an area off the coast of Portugal (see Fig. 1), which provided both strong oceanographic and topographic variability.

A new partner with expertise in SAR imaging (J. Small, DERA/United Kingdom) joined the program and in July of 1998 a new set of 4 experiments called INTIMATE 98 was conducted in the Bay of Biscay (see Fig. 2). This ensemble of experiments will allow us to look at source and environmental inversion in a variety of environments from deep to shallow water and with both flat and very complicated bottom topography (for instance, one site has high 'dunes' along the propagation path).

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1999**	2. REPORT TYPE	3. DATES COVERED **00-00-1999 to 00-00-1999**

4. TITLE AND SUBTITLE **Broadband Inversion in Shallow Water**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Science Applications International Corp,888 Prospect St., Suite 201,La Jolla,CA,92037**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

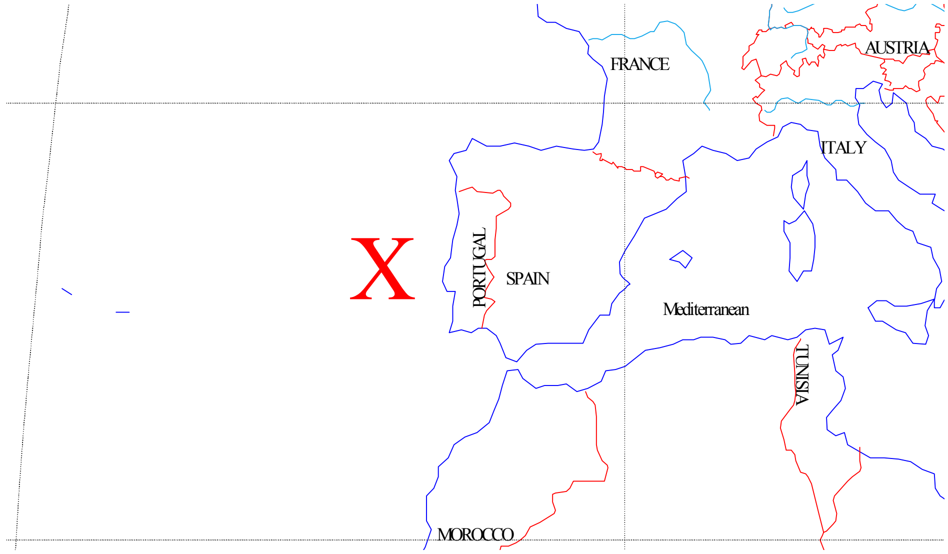

Figure 1. Location of the INTIMATE96 experiment.

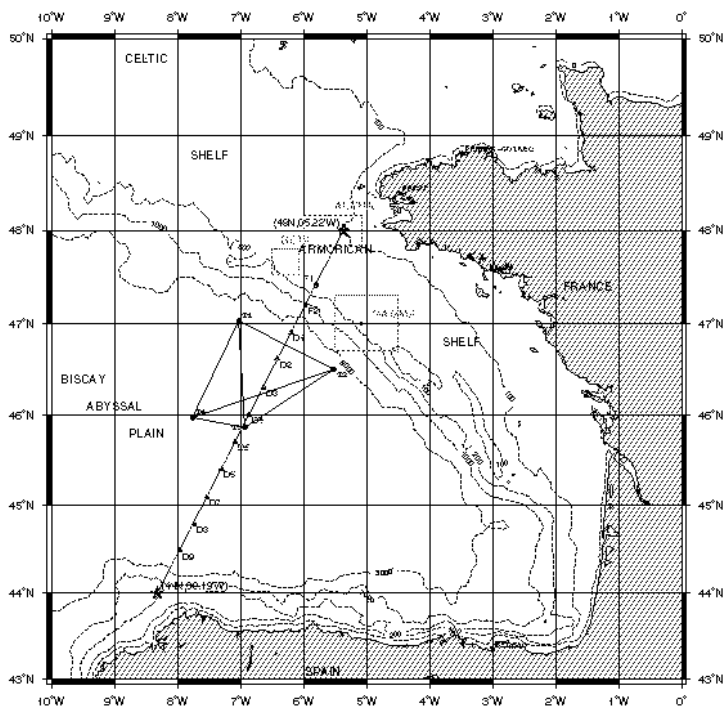

Figure 2: Location of INTIMATE 98 experiment.

Separately, in collaboration with NUWC (M. Tattersall and J.P. Ianniello) we studied an area near Key West with a steep slope so that we could look at the effects of horizontal-refraction that are currently poorly understood.

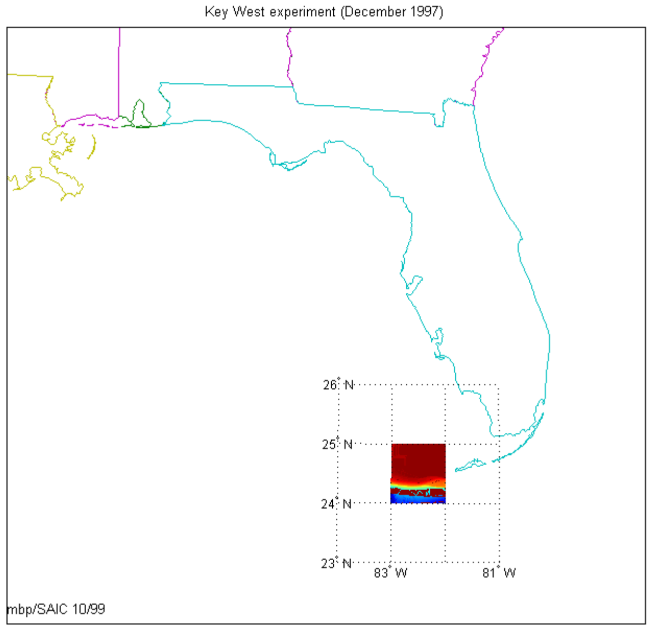

Figure 3: Location of Key West/LWAD 98 experiment.

Finally, in collaboration with SPAWAR SSC (J. Rice, V. McDonald, P. Baxley) I've been looking at high-frequency problems (8-16 kHz) appropriate for acoustic communications; intercept SONAR; and AUV tracking. Data from the May 99 ModemEx experiment has been studied for this component (this work was primarily supported by the ASEE summer faculty research program.)

WORK COMPLETED

I co-organized an international workshop with A. Caiti (Univ. of Sienna), S. Jesus (Univ. of Algarve), and J-P. Hermand (SACLANTCEN) on *Experimental Acoustic Inversion Methods* that brought leading researchers in this area together. The papers from this meeting are being edited in a special volume to be published by Kluwer. Through this and journal articles, reporting of the results of INTIMATE96 inversion of both the environment and the source position was largely completed in the last year [1-8].

Initial data processing from INTIMATE98 has been completed and shows a variety of different effects in each of the sites. For instance, the echo-gram from the Beta site in Fig. 4 shows the familiar striation pattern due to surface and bottom reflections. However, the multipath spread varies significantly due to what are most probably oceanographic effects. Similarly excellent datasets have been processed for all 4 of the sites and will be analyzed in the coming year.

Simulations of 3D effects were performed for the Key West experiment using an extension of the KRAKEN model that treats horizontal refraction using gaussian beams.

Finally, echo-grams were calculated for ModemEx99 data and communication performance was associated with features of the acoustic propagation paths.

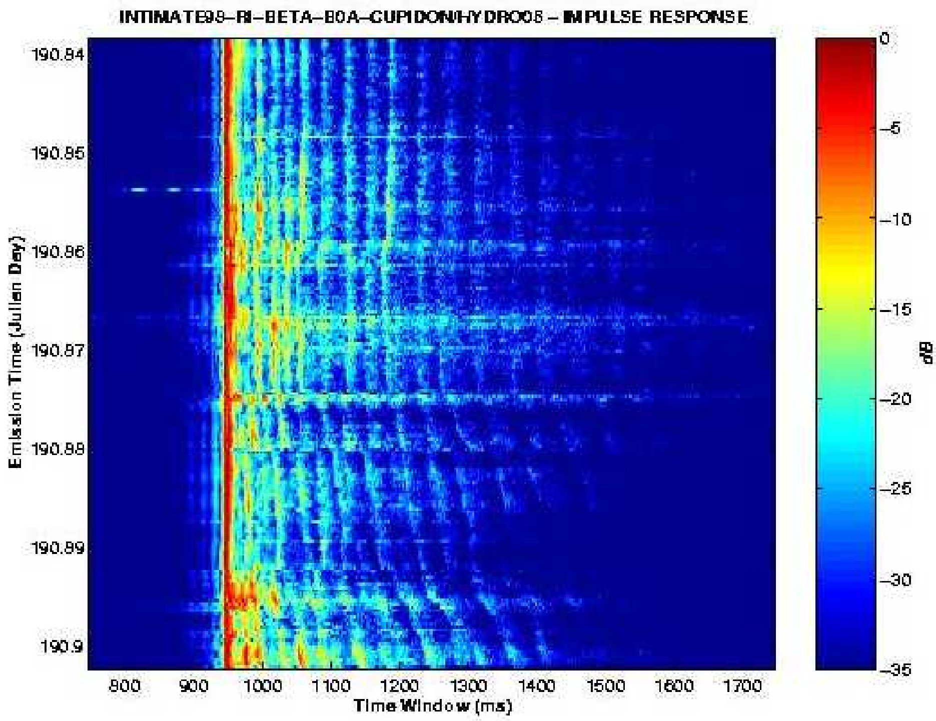

Figure 4: Echo-gram from the Beta site of INTIMATE 98.

RESULTS

The INTIMATE program has shown clearly the role of tides on acoustic propagation. Both INTIMATE96 and INTIMATE98 show a strong variation at the tidal frequency. Previous to these experiments most researchers in matched-field processing would have been skeptical of the possibility of tracking a source in such a higly-variable environment. However, based on the physics of the acoustic features we developed and verified a new log-envelope processor which has proven to be very robust. INTIMATE98 data is still being analyzed but we expect to confirm the reliability of the tracker in those sites.

Simulations for the Key West experiment [9] predicted horizontal-refraction of about 5 degrees in the cross-slope direction which is large-enough to be of interest for just planewave beamforming in the mid-frequency band. Interestingly, my collaborators at NUWC were able to perform model-based tracking using a 2D model without horizontal refraction (but did need to include range-dependent effects).

ModemEx 99 was particularly interesting to me since the frequency band was orders-of-magnitude higher than previous data we have studied. The data showed [10] that even at those high-frequencies

there was a clear multipath pattern; certainly less stable than what we have become accustomed to but almost certainly adequate for model-based tracking. Our main interest there; however, was in acoutic communications. Several interesting lessons were derived: first, the multipath spread varied in quite a complicated way with source receiver separation. In particular, the spread was reduced from 100 msecs to less than 10 msecs as the source reached a particular zone in the channel. Second, the bit-error-rate varied in a way that could clearly be associated with the propagation physics.

IMPACT/APPLICATIONS

INTIMATE has taught us a lot about how the tides affect acoustic propagation. More importantly, a correlation based tracker has been developed which is robust against these effects and may be useful for tracking AUV's and exploiting intercept signals.

The jury is still out on the importance of 3D effects but the magnitude of the refraction suggests that bearing errors may be large enough to be important for passive SONAR systems and this will certainly motivate further work.

The ModemEx results will be important in designing both coherent and incoherent signalling schemes The coherent schemes use the multipath structure for tap-placement and the incoherent schemes use it to select channel clearing-times. Finally, the stability of the echo-pattern indicates that model-based processing may be successfully applied for the higher-frequency band.

TRANSITIONS

Obviously the above projects are all being done in close collaboration with various navy laboratories and are thereby poised for transition to operational systems where appropriate. The correlator-tracker developed in INTIMATE will be studied in the coming year for the Kelp autonomous array system. Lessons on the role of horizontal refraction will be important for PACRANGEX95 and APB98 data analysis being conducted this year under a separate program.

The approach used in INTIMATE tracking is actually a form of time-reversal processing and we have pursued that separately with DARPA funding for "hyperthermia" which is the treatment of cancerous tumors by ultrasonic heating [11-16].

RELATED PROJECTS

INTIMATE is linked to the PRECOCE (PREdiction du comportement des Couches superficielles de l'Océan le long des Côtes Européenes) project which is designed to develop enhanced upper ocean models for European coastal areas. As mentioned above, the signal processing work is linked to Kelp (*ONR 321SS and SPAWAR SSC*) as well as PACRANGEX95 towed-array analysis (*ASTO*). The high-frequency work is related to the ModemEx99/00/01 acoustic communications program (*321OM and SPAWAR Telesonar Program*).

REFERENCES/PUBLICATIONS

1. Y. Stéphan, X. Démoulin, T. Folegot, S. Jesus, M. Porter, E. Coelho, “Influence de l’environnement sur la propagation acoustique par petits fonds: la campagne de tomographie acoustique INTIMATE96”, Numero 18, EPSHOM/CMO/OCA/NP report, Oct. 12, 1998.
2. S.M. Jesus, M.B. Porter, Y. Stéphan, E. Coelho, X. Démoulin, “Broadband source localization with a single hydrophone”, *Proceedings of Oceans ’98*, Sept. 28- Oct. 1, Nice, France (1998).
3. M.B. Porter, S.M. Jesus, Y. Stéphan, E. Coelho, X. Démoulin, “Using the echo pattern to range a sound source,” *Proceedings of the First International Symposium on Physics in Signal and Image Processing*, January 18-19, Paris, France (1999).
4. O. Rodriguez, S. Jesus, Y. Stephan, X. Demoulin, M. Porter, E. Coelho, “Nonlinear soliton interaction with acoustic signals: Focusing effects” *Proceedings of the Third International Conference on Theoretical and Computational Acoustics*, Trieste, Italy, (1999).
5. Seongil Kim, William A. Kuperman, Michael B. Porter, “Ray and beam shift in the time-domain” *Proceedings of the Third International Conference on Theoretical and Computational Acoustics*, Trieste, Italy, (1999).
6. S.M. Jesus, M.B. Porter, Y. Stéphan, X. Démoulin, O. Rodriguez, and E. Coelho, “Single hydrophone source localization”, submitted to *IEEE J. of Oceanic Engineering*, (1999).
7. Y. Stéphan, X. Démoulin, T. Folégot, S.M. Jesus, O. Rodriguez, M.B. Porter, E. Coelho, “Acoustic effects of internal tides on shallow water propagation: An overview of the INTIMATE96 experiment”, to appear in *Experimental Acoustic Inversion Methods*, Eds. A. Caiti, S. Jesus, J-P. Hermand, M.B. Porter, Kluwer (2000).
8. M.B. Porter, S.M. Jesus, Y. Stéphan, X. Démoulin , E. Coelho, “Tidal effects on source inversion”, to appear in *Experimental Acoustic Inversion Methods*, Eds. A. Caiti, S. Jesus, J-P. Hermand, M.B. Porter, Kluwer (2000).
9. M.B. Porter, J.M. Tattersall, and J.P. Ianniello, “Assessment of 3D effects in the Key West experiment”, presented at the *Third International Conference on Theoretical and Computational Acoustics*, Trieste, Italy, to be submitted to the Journal of Computational Acoustics (2000).
10. V. K. McDonald, J.A. Rice, Michael B. Porter, Paul A. Baxley, "Performance measurements of a diverse collection of undersea, acoustic, communication signals", *Proceedings of Oceans'99*, (1999).
11. P. Roux, M.B. Porter, H.C. Song, W. Kuperman, “Hyperthermia therapy using phase conjugation,” *J. Acoust. Soc. Am.*, Vol. **105**(2):1117, Pt. 2 (1999).
12. Philippe Roux, Michael B. Porter, Hee C. Song, William A. Kuperman, “Hyperthermia therapy using phase conjugation”, 137th Meeting of the Acoustical Society of America/2nd Convention of the European Acoustics Association, Berlin, Germany (1999).

13. Philippe Roux, Michael Porter, Hee Chun Song, and W.A. Kuperman, “Application of phase conjugation to hyperthermia therapy”, *Proceedings of 24th International Symposium on Acoustical Imaging*, Ed. Hua Lee, held Sept. 23-26, Univ. of California at Santa Barbara, Plenum Press, (1999).

14. Philippe Roux, Michael Porter, Hee Chun Song, and W.A. Kuperman, “Hyperthermia therapy using acoustic phase conjugation”, to appear *Proceedings of the First International Symposium on Physics in Signal and Image Processing*, January 18-19, Paris, France (1999).

15. M. Porter, P. Roux, H. Song, and W. Kuperman, “Tumor treatment by time-reversal acoustics”, *International Conference on Acoustics, Speech, and Signal Processing (ICASSP) Proceedings*, Vol. **4**, p. 2107-2110 (1999).

16. P. Roux, H.C. Song, M.B. Porter, and W.A. Kuperman, “Application of the Parabolic Equation Method to Medical Ultrasonics”, in press, *Wave Motion* January (1999).